International Environmental Modelling and Software Society (iEMSs)
2010 International Congress on Environmental Modelling and Software
Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada
David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.)
http://www.iemss.org/iemss2010/index.php?n=Main.Proceedings

Agent-based model of the growth of an informal settlement in Dar es Salaam, Tanzania: An empirically informed concept

Gina Felicia Young[a], Johannes Flacke[a]
[a] *Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, The Netherlands (young22246@itc.nl, flacke@itc.nl)*

Abstract: The paper discusses the use of empirical evidence to derive the concept for a spatially explicit agent-based model that simulates land-use change in an informal settlement in the city of Dar es Salaam, Tanzania. Dar es Salaam's informal settlements are home to 70 – 80 % of the city's residents and are characterized by high housing densities, unstructured road infrastructure and inadequate water, electricity, and sewerage services. However, they differ from typical Sub-Saharan informal settlements in two main ways: First they consist of residents with varying socioeconomic backgrounds, specifically income, education, and type of employment. Second, plots of land are not squatted on. The main purpose of the research is to develop the concept for an agent-based model for informal settlement growth derived from empirical findings. The model concentrates on the economic aspects of the spatial growth, but also includes other socioeconomic and biophysical elements. Empirical evidence on household behaviour was acquired via a questionnaire survey in which data on personal details, plot and house details, location preferences, and the housing development process was obtained.

Keywords: informal settlement growth; housing; evidence driven agent-based model

1. INTRODUCTION

In Dar es Salaam, Tanzania, the lack of state intervention and failure in planning policies in informal settlements has encouraged the informal sale and distribution of land by private individuals and the subsequent construction of housing. With the continued informal purchase and sale of land, it is understood that the emergent phenomenon of growth of informal settlements in Dar es Salaam is the result of individual and household decision-making. The decision to alter, extend, or construct a new housing structure may result from varying levels of dissatisfaction with present housing conditions, but is also highly dependent on the household's financial capabilities [Seek 1983].

Aim of the paper is to present the concept for an agent-based model for informal settlement growth derived from empirical findings. Notwithstanding the capacity of other types of models such as cellular automata to simulate changes in urban land-use and land cover, an agent based model's ability to simulate individual behavior is where its advantage lies in capturing informal processes, household dynamics, and their effects on urban and peri-urban land-use change. In an informal setting such as this, understanding individual behavior forms an intricate part of understanding settlement dynamics.

2. GROWTH OF INFORMAL SETTLEMENTS

High population densities combined with rapid, uncontrolled growth in informal settlements pose a problem for city administrators as their capacity to keep pace in providing infrastructure and public services to residents is severely strained. In cities such as Nairobi and Cairo, for example, problems associated with informal settlements include lack of usable open spaces, inadequate drainage and sewerage, limited road, pathway, and water infrastructure, poor environmental conditions and high crime rates [Alder 1995, El-Batran and Arandel 1998, EN Habitat 2008].

2.1 Case study Dar es Salaam

Dar es Salaam's (estimated 3.5 Mio. inhabitants 2000) informal settlements are home to 70-80 % of the city's residents and are characterized by high housing densities, unstructured road infrastructure and inadequate water, electricity, and sewerage services. However, they differ from typical Sub-Saharan informal settlements in two main ways: First they consist of residents with varying socioeconomic backgrounds, specifically income, education, and type of employment. Second, plots of land are not squatted on; originally the early settlers had de facto ownership over the land through the customary land tenure, while later, as the land was included in the urban administration, an informal land market developed through which the settlers most commonly purchased a plot [Kyessi 1993].

For the development of the model concept, the informal settlement of Hanna Nassif in Dar es Salaam was chosen as a case study. The settlement is located approximately 4.5 km from the city centre and is bounded on the north by a planned residential area, to the west by Kawawa road; the Msimbazi river valley forms its southern and eastern borders [Sheuya 2004]. The settlement is one of the oldest in Dar es Salaam, having been established in the 1960's [Sliuzas 2004]. It comprises mostly low-income residents (ibid). In 2002, its population was estimated at 13,000 inhabitants. Its areal coverage is around 62.5 ha, rendering a population density in 2002 of 210 persons/ha. Based on the Tanzanian census of 2002 [The United Republic of Tanzania 2002] which quotes an average household size of 4.2, the number of households in Hanna Nassif in 2002 was approximately 3,100.

2.2 Drivers of informal settlement growth in Dar es Salaam

Rapid urbanization in Dar es Salaam has been attributed to sustained increases in rural-urban migration (2-3 % p.a.) coupled with a high birth rate. In Tanzania, the urban population grows at an average of 6 % per annum, twice that of the national average [World Bank 2002]. Due to increasing levels of poverty, population growth and lack of sustainable housing policy, urban growth is absorbed into informal settlements (ibid). Absorption of the population into informal settlements, on the one hand, is due to the lack of provision of formal or surveyed plots for the greater portion of the urban population. Kombe and Kreibich [2000a] mention 6.8 % of plot allocations fulfilled between 1978/79 and 1990/91 in the city of Dar es Salaam; Kironde [2006] states approximately 3.4 % of the demand satisfied between 1990 and 2000.

The incidence of informal settlements in Dar es Salaam also results from deficits in the statutory planning system in Tanzania since long [Kombe and Kreibich 2000b]. For instance the three master plans developed between 1945 and 1979 were dependent on imported planning expertise, ideologies, assumptions, values and mechanism, advocated for racial segregation, and demonstrated colonial lack of concern for the needs of African residents [Sliuzas 2004]. As a result, native residents were continually absorbed in informal areas – a phenomenon which has persisted ever since.

3. EMPIRICAL RESULTS

The main instruments used in the study were a literature analysis and a written household questionnaire survey. Additionally, secondary sources were sought for data on macroeconomic variables. The literature analysis served to identify macroeconomic policies that were implemented during the development of the settlement which had the potential to influence housing construction volume. Data on macroeconomic variables such as inflation rate and real effective exchange rate was obtained for comparison in relation to policy implementation. The household questionnaires survey was administered to 38 house owners within the settlement during October/November 2009. Average household income for respondents ranged from low to high, i.e. 18.5 % < TShs 30,000, 16.3 % TShs 30,001 – 90,000, and 55.2 % > TShs 90,000. Responses from the survey served to inform the micro-level decision-making behaviour in residential location and household economic activities.

3.1 Macroeconomic policies influencing informal settlements growth

The implementation of macroeconomic policies in Tanzania was conducted in particular episodes with varying levels of success and effect on macro-level economic variables. Three main policy periods were identified: social policy and inward reform episode, episode for policies targeted at efficiency and economic growth, and the final synthesis episode where both social and growth policies were combined.

Nineteen seventy to 1978 marked the first half of the social policy and inward reform episode. During this time the state played a major role in the country's economy [Li and Rowe 2007]. The inflation rates averaged around 11 % [IMF 2009] and the real effective exchange rate was about 105% of the 2000 forex rate (Figure 1). From the 38 households interviewed in the 2009 household survey, around 26 % of 168 new rooms were built during this period (Table 2). The second half of this period ran from 1979-1985. During this time the inflation rate rose to an average of just over 28 % and the real effective exchange rate rose to 154 % of the 2000 rate. Construction of new rooms during this time only comprised around 14 % of the total.

The second policy episode ran from 1986-1993. Policies implemented during this time targeted efficiency and economic growth. Two main economic recovery programs were implemented. The first was aimed at increasing efficiency and restoring economic growth, reducing inflation and fiscal deficits, realigning the exchange rate, and improving the balance of payments by increasing exports and foreign exchange earnings [World Bank 2002]. However, this era was marked by maintained high inflation rates which averaged about 30 % annually. The real effective exchange rate was not as high as other periods: 92 % relative to the 2000 exchange rate. The effective of high inflation was sustained low construction activity; only about 20 % of new rooms were constructed during this time. The programs implemented during this time, however, had a positive impact on the macro-economic conditions, which became evident in the following era.

The third episode ran from 1994-2004. This episode sought to combine the strategies attempted in previous periods and initiatives attempted during this time were therefore termed "initiatives to combine growth and social policy". These initiatives coupled with those in the latter stages of the efficiency and growth episode were effective in reducing the average inflation rate to an average of approximately 8 %; the real effective exchange rate was kept at 90% relative to the 2000 exchange rate. This phase of reduced inflation rates saw an increase in construction of housing structures. From the responses obtained in the household survey, over 40 % of new rooms were built during this period.

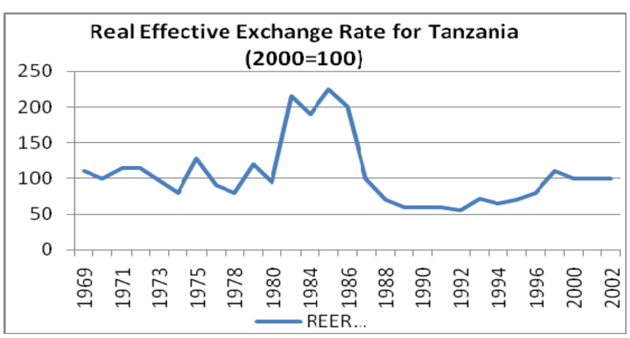

Figure 1: Tanzania real effective exchange rates

Table 1: Construction activity per policy episode

Policy period	Inflation (%)	REER (2000=100 %)	No. of rooms built	Percentage (168=100 %).
1967-1978	10.7	105	43	25.6
1979-1985	28.3	154	23	13.7
1986-1993	28.9	92	34	20.2
1994-2004	8.1	90	68	40.5

3.2 Micro-level economic activity and residential location decision making

Micro-level household behaviour pertaining to housing development was determined mainly from the data attained from the 2009 survey. The main elements covered under this section of the study were the socioeconomic triggers of housing construction, household budget constraint, factors that contribute to location decision-making, biophysical constraints which negatively affect location choices, and the preferred socioeconomic structure of neighbourhood residents.

Prices at which settlers purchased a lot to build a house range between \$34 (present value TShs 45,000) to \$455 (TShs 606,000).The main trigger of housing construction by owners was found to be the accommodation of children and other relatives. Approximately 70 % of respondents cited this as the reason for building the house they currently reside in. The budget constraint describes the set of options of ‘goods’ that is available to the household. This was determined in order to ascertain the portion of household income that is geared toward housing provision. Almost 74 % of respondents cited savings from income as the source of funding for housing. From the income, a certain percentage was spent on monthly expenditures; the remaining portion is considered surplus. From the surplus a portion is spent on irregular items such as extra food, entertainment, etc. and the remainder is saved for housing development. While the range of values was large (0-100 %), the median and mean percentages saved for housing were both 70 %. The budget constraint for a household intent in construction can be represented as:

Savings for housing construction = (*monthly income – household expenditure*) x (*0.7*)

More than 60 % of respondents claimed to use the saved money for either supplementing new rooms to current structures or building new houses.

The main factors that attract households to particular locations were found to be proximity to water points, roads, footpaths, local market, and bus stop, with priorities for water points, roads, and footpaths. These elements cover preferential factors for all households, not any agent in particular. Constraints avoided in location decision-making were flood prone areas, steep slopes, and swamps. The main characteristic of neighbours that house owners found attractive was similar income, and to a lesser extent similar type of occupation, i.e. residents prefer to reside in locations where neighbours were from a similar socioeconomic group.

4. THE CONCEPTUAL MODEL

The model is comprised of two main levels – micro and macro (Figure 2). At the micro-level (or local level), there are two modules which detail the actions taken by household agents when intending on constructing houses. The agent transformation module holds the agents’ state and models the transitions of the agent in terms of the attributes they possess, such as tenure and number of children. The decision-making module details the steps taken when an agent is seeking a plot on which to construct a house. The modules culminate in the household agents settling. The combined effect of settling is the macro-level emergent growth of the settlement. The model is fed and manipulated by global parameters which serve as experimentation mechanisms for the model. The overview also shows how the settling of agents affects the characteristics of the spatial environment which in turn affect decision-making and ultimately the spatial growth pattern of the settlement. This feedback mechanism is important for the proper modelling of the system.

4.1 Agents

Household agents were categorized by form of employment and tenure status. Owner households were found to be arising from both tenant households and existing owner households. Also, the study revealed that there is a clear difference in behavioral patterns between households headed by an individual with formal employment and one headed by an individual with self (or informal) employment. Differences pertain to location preferences and constraints, and other characteristics such as household threshold size, lot price ranges, and house size (number of habitable rooms).

Based on the above means of categorization, four main household agents were identified:

1. Tenant households with formal employment,
2. Owner households with formal employment,
3. Self-employed tenant households, and
4. Self-employed owner households.

Additionally, the building polygons are modeled as fixed, immobile agents with dynamic attributes. Thus vacant and developed building polygons are identified as additional agents.

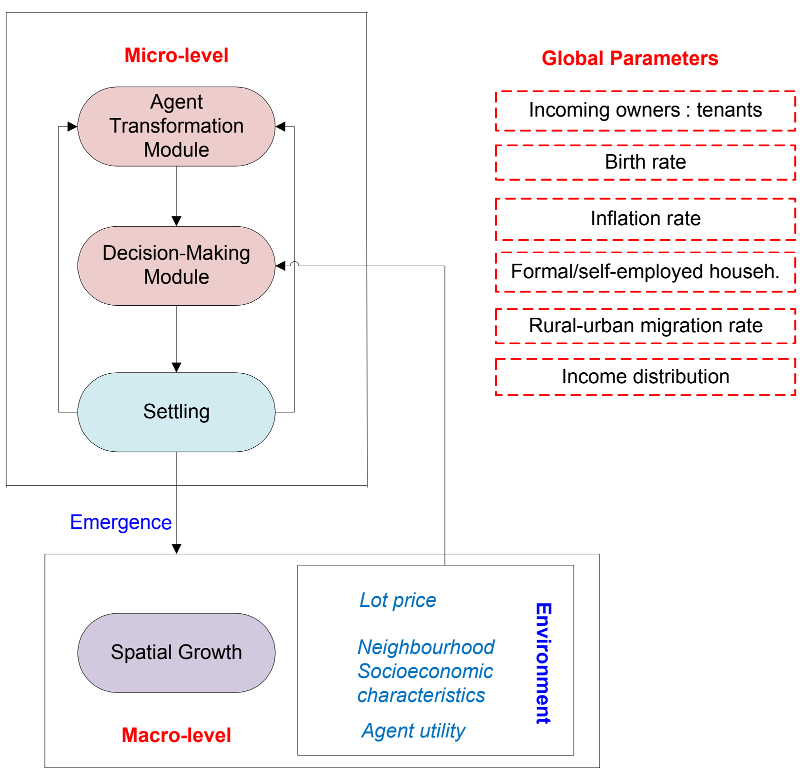

Figure 2: Model overview

4.2 Model elements on the micro-level

Figure 3 shows the procedural steps a household agent takes toward housing development.

The **agent transformation module** holds agent states and contains information used to determine when the agent is ready to enter the decision-making module. The attributes or variables such as form of employment, income, tenure status, and number of children collectively comprise the agents' state. As an example, an agent starts off as a starter tenant household having a household size of 2. As the family size increases the need for space increases within the housing structure, so the household begins saving for own housing. The actions of extending structures and building second structures on the same plot are also triggered by the agent information stored in this module. When the threshold number of children is reached, the agent is triggered to enter the decision making module; the agent seeks a plot on which to construct a house.

From the set of available location options, the agent perceives the environment and chooses the polygon with the highest utility value, within its budget constraint, and where the neighboring residents have similar income and/or occupation (**decision making module**). This choice is made possible through the attributes provided for each polygon within the environment. If the necessary conditions are met in any of the plots found available then the agent purchases the plot and commences construction. If the conditions are not met, then the agent goes through the cycle again. The number of iterations allowed at each time step will depend on the volume of construction expected and will be determined when the computer model is calibrated.

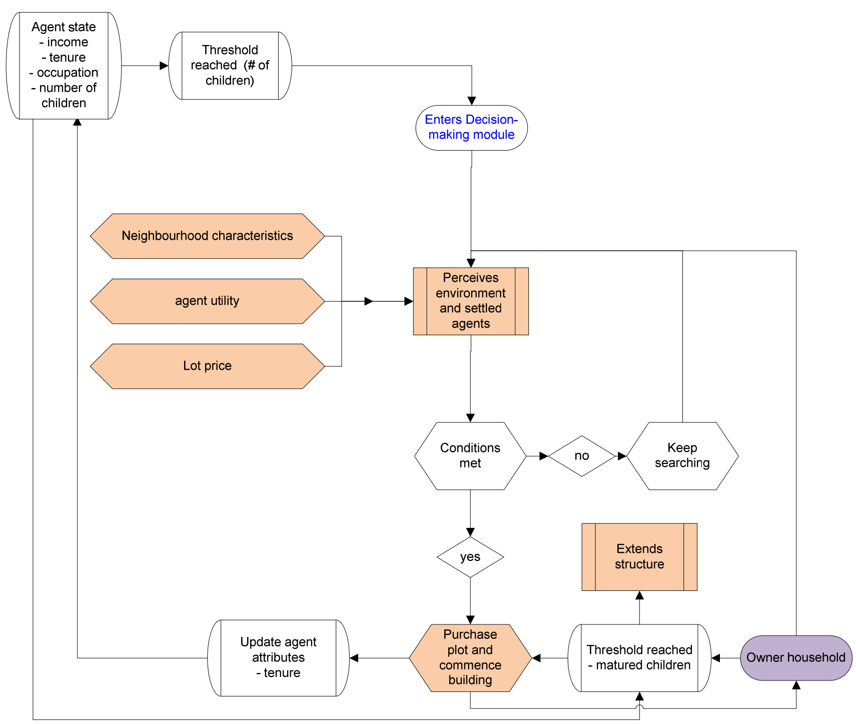

Figure 3: Micro-level Agent transformation and Decision making modules

4.3 Macro-level

The macro-level of the model represents the global spatial growth of the settlement and results from the collective settling activity of household agents. The growth in this context is comparable to the notion of emergence which, in complexity theory, is the manner in which simple interactions give rise to complex systems and patterns. The ability to adjust the global parameters which feed the system allows for experimentation via the model, resulting in varying spatial form outputs.

The environment is spatially explicit, having the geographical locations of infrastructure, services, and biophysical constraints within. Given the irregular layout of road and footpath infrastructure, and thus the building polygons, the model is designed within a vector environment. Although raster may have computational advantages, it will not adequately represent the spatial layout of the settlement, which is important to local decision makers [Augstuijn et al. 2009]. The location of infrastructure such as roads and public service facilities will remain static.

Each polygon represents occupied or undeveloped building polygons. Polygons are modelled as immobile agents, each having the following dynamic attributes:

- Agent utility values
- Estimated relative lot price
- Agent income range
- Agent occupation type
- Availability

The relative lot price is estimated by averaging the utility values for each plot for the different agents along with the relative welfare associated with presence of proper drainage. The utility values are based on agent location preferences and biophysical constraints identified from the analysis of micro-level household behavriour. Since the agent has to make a location decision based on utility, lot price, and socioeconomic background of neighbours, these three elements are kept separate. These three conditions need to be met, following an if-then command in the decision-making module, before the agent chooses a location.

The function used to determine agent utility is the following:

$$U_{r(x,y)} = \sum_{i=1}^{m}(1-\gamma) + \sum_{i=1}^{n}(1+\ \delta) \tag{1}$$

Both factors and constraints contribute to agent utility associated with each location. In **Equation 1** where the utility *U* for each agent *r* is determined, *m* represents the number of factors and *n* represents the number of constraints considered for location *i*; γ represents the standardized distance value from each factor, while δ represents the standardized distance from each constraint. There are 2 factors and 2 constraints considered for each agent. Distance values are calculated using the Near function in ArcGIS then the values are standardized around the maximum. Weights applied to each factor and constraint is assumed to be the same. For the formally-employed agents, the main factors considered were the bus stop and secondary roads, while for the self-employed agents the main factors were roads and nearest local market. Equation 1 was perceived to be adequate for calculating agent utility as it captures the advantages of close proximity to preferential factors and distance away from constraints.

4. CONCLUSIONS AND RECOMMENDATIONS

The concept for an agent based model presented here is the first and most crucial step toward building a computer model. It constitutes part of an ongoing initiative being implemented in stages. The next immediate step is to translate the concept into computer code, which may identify areas for improvement and amendment.

The computer model should be able to model land-use change in Hanna Nassif. The provision of global parameters allows any user to visualize spatial results of modeling under current demographic and economic trends, as well as under probable changes that may result from government or other forms of intervention. For example, the construction of road infrastructure or provision of public services in certain locations would affect agent decision-making and thus produce a different result on spatial form. Different outcomes can be explored in this manner. In this context, the model serves mainly as a visualization and experimentation tool that should support local decision-making.

ACKNOWLEDGMENTS

The authors like to thank Richard Sliuzas for valuable comments during the development of the conceptual model. Special thanks go to Flavia Feitosa, Tatiana Filatova, Friedrich Krebs, and Volker Kreibich for kindly reviewing the conceptual model as subject matter experts. Gina Young thanks EU for enabling the study visit at ITC, Enschede, The Netherlands, within Erasmus Mundus (Lot 10) External Cooperation Window Programme.

REFERENCES

Alder, G., Tackling poverty in Nairobi's informal settlements - developing an institutional strategy, *Environment and Urbanization 7(2)*, 85-107, 1995.

Augustijn, P.W.M., J. Flacke, and A Iqbal, Simulating informal settlements growth in Dar es Salaam, Tanzania; a hierarchical framework, paper presented at the 3rd ICA Workshop on Geospatial Analysis and Modeling, Gävle, Sweden, August 6-7, 2009.

El-Batran, M. and C. Arandel, A shelter of their own: informal settlement expansion in Greater Cairo and government responses, *Environment and Urbanization, 10(1),* 217-232, 1998.

IMF, Tanzania: Inflation, average consumer prices (annual percent change), Retrieved May 16 2010 from http://www.imf.org/external/pubs/ft/weo/2009/02/weodata/weorept.aspx?sy=1980&ey=2004&scsm=1&ssd=1&sort=country&ds=.&br=1&c=738&s=PCPI%2CPCPIPCH&grp=0&a=&pr1.x=62&pr1.y=10.

Kironde, L.J.M., The regulatory framework, unplanned development and urban poverty: Findings from Dar es Salaam, Tanzania, *Land Use Policy, 23(4),* 460-472, 2006.

Kombe, W. J. and V. Kreibich, Informal land management in Tanzania, SPRING Research Series (29). Dortmund, 2000a.

Kombe, W.J. and V. Kreibich, Reconciling informal and formal land management: an agenda for improving tenure security and urban governance in poor countries, *Habitat International 24(2),* 231-240. 2000b.

Kyessi, S., Analysis of the physical and socio-economic characteristics of Manzese squatter settlement Dar es Salaam: a case of Lake Magomeni area, MSc. thesis, ITC Enschede, 1993.

Li, Y. and F. Rowe, Aid Inflows and the Real Effective Exchange Rate in Tanzania, World Bank, 2007.

Seek, N.H., Adjusting Housing Consumption: Improve or Move, *Urban Studies 20(4),* 455-469, 1983.

Sheuya, S., Housing Transformations and Urban Livelihoods in Informal Settlements - The case of Dar es Salaam, Tanzania,Ph.D. thesis, University of Dormund, 2004.

Sliuzas, R.V., Managing informal settlements: a study using geo-information in Dar es Salaam, Tanzania, Ph.D. thesis, Utrecht University and ITC Enschede, 2004.

The United Republic of Tanzania, 2002 Population and Housing Census, Retrieved July 1 2009, from http://www.tanzania.go.tz/census/dsm.htm.

UN-Habitat, UN-Habitat and the Kenya Slum Upgrading Programme - strategy document, Nairobi, 2008.

World Bank, Tanzania at the turn of the century: Background papers and statistics, The World Bank Country Study, Washington D.C., World Bank, 2002.

World Bank, Upgrading Low Income Urban Settlements, Country Assessment Report, Tanzania, Retrieved July 1, 2009, from http://web.mit.edu/urbanupgrading/upgrading/case-examples/overview-africa/country-assessments/reports/Tanzania-report.html.